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DOWNEY PLANT

RESEARCH DIVISION

PROJECT SOPHY

SOLID PROPELLANT HAZARDS PROGRAM

Technical Documentary Report No.
AFRPL-TR-66-24

Progress Report On
Contract AF 04(611)-10919

Report Number 0977-01(02)QP / March 1966 / Copy 192

AEROJET GENERAL TIRE **GENERAL**

AEROJET-GENERAL CORPORATION
Research Division
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Downey, California

PROGRESS REPORT

PROJECT SOPHY

SOLID PROPELLANT HAZARDS PROGRAM

Technical Documentary Report No.
AFRPL-TR-66-24

Contract AF 04(611)-10919

0977-01(02)QP

Period Covered: 1 December 1965 - 28 February 1966

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1.   INTRODUCTION

This quarterly progress report is the second of a series which partially fulfills Contract AF 04(611)10919, Large Solid Propellant Boosters Explosive Hazards Study Program.   The purpose of this program is to gain additional knowledge and to develop new techniques for analyzing the explosive hazard and damage potential of large solid-propellant rocket motors.

The objectives of this program are: (1) to determine the influence of grain shape on propellant detonability and sensitivity, (2) to determine the critical diameter of a typical solid rocket-motor propellant, (3) to determine what changes a solid propellant grain might undergo when exposed to operational mishaps, and (4) to develop methods to simulate and characterize these alterations.

2.   SUMMARY

o   Air Force approval of the program plan, Reference 1, was received 8 December 1965.

o   The RUBY computer code has been successfully applied to ammonium perchlorate, RDX, and RDX-wax. A revision of RUBY is being acquired which will allow the formation of more than one solid product by the reaction.

o   The variance and critical geometry tests of AAB-3189 have been delayed because of casting-line difficulties in preparing the RDX-adulterated material.

o   Critical diameter and variance tests of one batch of AAB-3225 have been completed. From the test results, the critical diameter is 5.21 in. and the experimental standard deviation is 0.06 in.

o   Preliminary tests in the development of a probe system for measuring reaction-zone thickness in a detonating charge have shown encouraging results.

o   The explosive booster and propellant acceptor segments have been cast for the 72-in. critical-diameter test scheduled for late March. All handling hardware, lifting fixtures, restraining fixtures, and other tooling have been completed and checked out.

o   The first 2500-lb TNT calibration charge has been cast for
the instrumentation checkout and calibration shot which will
be fired in early March.   The test will be repeated, using a
second charge, after the 72 in. test has been performed.

3.   THEORY OF CRITICAL GEOMETRY

3.1   THEORETICAL PROGRAM

3.1.1   Ammonium Perchlorate Detonation Properties

After considerable analysis of the RUBY program in an effort to discover
the cause for its failure to provide a solution for the ammonium
perchlorate (AP) detonation properties, the trouble was located and
identified as an error in input.   The error was corrected, and satis-
factory solutions were generated for ammonium perchlorate at each of
several loading densities.   Computed detonation properties for AP at
densities of 1.50 and 0.08 g/cm^3 are presented in Table 1.

These values are in agreement with the results calculated for ammonium
perchlorate by Evans, et al, (Reference 2), using RUBY.   The particular
loading densities chosen by Aerojet unfortunately did not coincide with
those selected in Reference 2.   To make a comparison between the two
sets of data would require interpolation.   Evans, et a., report an ideal
detonation velocity for AP of 3.67 mm/μsec at a loading density of
0.75 g/cm^3 and 4.13 mm/μsec at 0.95 g/cm^3.   The Aerojet calculations
yielded a velocity of 3.82 mm/μsec at a loading density of 0.080 g/cm^3,
and an interpolated velocity of 4.20 mm/μsec at 0.95 g/cm^3.

The small differences between the two sets of calculations may result
from the differences in the covolume inputs used, since some uncertainty
exists as to the correct covolume values for specific compounds.
RUBY is particularly sensitive to covolume input values.   The values
used in the work by Evans, et al, are not reported.   Those used in the
Aerojet calculations are given in Table 2.

Table 1. RUBY Calculations for Ammonium Perchlorate.

Property	Units	$\rho_0 = 0.80$ g/cc	$\rho_0 = 1.50$ g/cc
D	mm/μsec	3.824	5.554
P_{C-J}	Mbar	0.032	0.110
T_{C-J}	10^3 °K	1.227	0.795
ρ_{C-J}	gm/cc	1.105	1.968
γ	(dimensionless)	2.621	3.208
$E_{C-J} - E_0$	cal/gm HE	133.3	208.1
$S_{C-J} - S_0$	cal/°K/gm/HE	-0.346	-0.834
Σ moles gas	10^{-3} moles/gm HE	36.32	36.32
V_g	cc/mole	24.91	13.99

Composition

H_2O	10^{-3} moles/gm HE	12.82	12.82
N_2	10^{-3} moles/gm HE	4.27	4.27
O_2	10^{-3} moles/gm HE	10.68	10.67
NO_2	10^{-3} moles/gm HE	0.00	0.01
HCl	10^{-3} moles/gm HE	8.56	8.55

Symbols

D	detonation velocity
ρ, T, γ, E, S, V	standard thermodynamic quantities

Subscripts

C-J	Chapman-Jouguet conditions
o	original condition
g	gas

Table 2. Covolumes Used in RUBY Code Calculations.

Product	RDX-Wax	Ammonium Perchlorate
H_2O	360	250
H_2	180	180
CO_2	670	-
N_2	380	380
O_2	350	350
NO_2	600	600
NH_3	476	476
CH_4	528	-
HCl	-	643

Experimental detonation velocities for AP, at various densities and charge diameters, are reported by Andersen and Pesante (Reference 3). At a loading density of 0.80 g/cm^3 and a charge diameter of 4 in. the detonation velocity was observed to be 3.0 mm/μsec. Furthermore, from the shape of their velocity-diameter curve, ranging from a diameter of 0.75 in. to the 4 in., it appears that 3.0 mm/μsec approaches the ideal detonation velocity. The RUBY program is approximately 25% high with its calculation of 3.82 mm/μsec.

Three separate experimental values are reported in Reference 3 for AP detonation velocity at a packing density of 1.50 g/cm^3. The values were obtained from 2.5 in. diameter samples, and averaged to 4.3 mm/μsec. No evidence is given to indicate that 2.5 in. is near the ideal diameter at this density, therefore data are not to be compared with the predicted 5.55 mm/μsec ideal velocity.

3.1.2   RDX-Wax Detonation Properties

RUBY calculations also have been made for an explosive composed of 30 wt % RDX and 70 wt % wax - a material similar to that which was used in the AF 04(611)9945 program. The purposes of making these calculations were: (1) to compare the experimental detonation-velocity results obtained in the nonideal region with the calculated ideal detonation velocity, and (2) to test the ability of RUBY to handle a composition similar to a composite propellant -- fast-reacting oxidizer distributed in a slow-reacting fuel. The results of these computations are given in Table 3.

The detonation-velocity vs diameter relationship of RDX-wax (Reference 4) indicates that the ideal detonation velocity is greater than 6.5 mm/μsec (D = 6.57 mm/μsec at d = 1.75 in. for the material, which has a critical diameter of approximately 1.5 in.). The upper bound would appear to be 7.2 mm/μsec. This is based on an extrapolation of the data which is influenced by the fact that the velocity-diameter function for this type of material closely approaches its asymptote D_i at diameters $d \geq 2\ d_c$. The RUBY program predicts an ideal detonation velocity of 6.9 mm/μsec when the input parameter, heat of formation of graphite, is chosen to be zero (Table 3). With the heat of formation of carbon chosen to be 10.75 kcal/ mole, as it has been for SR1 and NOTS, RUBY predicts an ideal detonation velocity of 6.2 mm/μsec. The first computation which argees with the experimental evidence is encouraging and indicates that RUBY can handle a propellant-like material as well as the high explosives, for which the program was originally written.

Table 3.   RUBY Calculations for RDX-Wax.

$$\rho_o = 1.11 \text{ g/cc}$$

Property	Units	ΔH_f of Graphite = 0.0 Kcal/mole	ΔH_f of Graphite = 10.75 Kcal/mole
D	mm/μsec	6.906	6.211
P_{C-J}	Mbar	0.123	0.091
T_{C-J}	10^3 ^{o}K	1.058	0.707
ρ_{C-J}	gm/cc	1.444	1.408
γ	(dimensionless)	3.315	3.729
$E_{C-J} - E_o$	cal/gm HE	306.5	206.1
$S_{C-J} - S_o$	cal/^{o}K/gm/HE	-0.844	-1.112
Σ moles gas	10^{-4} moles/gm	349.168	351.437
V_g	cc/mole	15.89	16.76
Composition			
H_2O	10^{-4} moles/gm HE	80.993	39.776
H_2	10^{-4} moles/gm HE	0.002	--
CO_2	10^{-4} moles/gm HE	0.003	20.612
N_2	10^{-4} moles/gm HE	35.816	40.376
NH_3	10^{-4} moles/gm HE	9.368	0.248
CH_4	10^{-4} moles/gm HE	222.967	250.425
C (graphite)	10^{-4} moles/gm HE	--	269.962
C (diamond)	10^{-4} moles/gm HE	318.029	--

Symbols

D	detonation velocity
ρ, T, γ, E, S, V	standard thermodynamic quantities

Subscripts
    C-J   Chapman-Jouguet conditions
    o   original condition
    g   gas

The low, 1058°K, C-J temperature, predicted by RUBY, is of some concern. However, the extremely low oxygen content in the material does suppress the reaction kinetics and may do so to sufficiently account for this temperature. Since no experimental measurement of this temperature has been made, it is not possible to reject the value calculated by RUBY.

3.1.3   AP-Binder Systems Detonation Properties

A later version of the RUBY code is being obtained from the Naval Ordnance Test Station (NOTS), China Lake, California. This program, in conjunction with NOTS thermodynamic data, has been successfully used to calculate the ideal detonation properties of several AP-binder systems. It is intended to use this program and the NOTS data to calculate the ideal detonation properties for an RDX-adulterated AP-PBAN composition (AAB-3189) and an unadulterated AP-PBAN composition (ANB-3226). Detonation velocities in the adulterated material will be measured experimentally, to diameters in excess of 4 d_c (Subtask 3.2.3).

3.1.4   Estimation of Density-Variation Effect on Parameter c

In the theory developed under AF 04(611)9945,

$$d_c = k_1 + k_2 (f + c)^{-1/3} \tag{1}$$

where d_c is the critical diameter of a propellant material containing f weight fraction RDX, and k_1, k_2, and c are constants. The parameter c represents the excess weight fraction RDX that would exist if all effective voids* were replaced by RDX particles of comparable size. It can be shown that if W_R = actual weight of RDX and W_R' = weight of RDX "added",

$$c = \frac{1 + \left(\dfrac{W_R'}{W_R}\right)}{\left(\dfrac{1}{f}\right) + \left(\dfrac{W_R'}{W_R}\right)} - f \tag{2}$$

---

*"Effective voids" means those voids capable of becoming initiation sites by shock-compression.

Furthermore, the quotient term can be expressed by

$$\frac{W'_R}{W_R} = \left(\rho_R / \rho_o\right)\left(\frac{1}{f}\right) N_v \bar{V}_v \tag{3}$$

where

ρ_R = density of RDX

ρ_o = porous propellant density

N_v = number of effective voids per unit volume

$\bar{V}_v$ = average volume of the effective voids

From Equation 32 in Reference 5, the distribution of voids can be expressed by

$$N = n_p \exp\left(-V/V_a\right) \tag{4}$$

where

N = number of voids per unit volume greater than volume V

n_p = total number of voids per unit volume

V_a = the average void volume

If V_i is the minimum effective void volume,

$$N_v = n_p \exp\left(-V_i/V_a\right) \tag{5}$$

The average void size, $\bar{V}$, over any interval can be calculated from

$$V = \int_{V_1}^{V_2} V\, f(V)\, dV \Bigg/ \int_{V_1}^{V_2} f(V)\, dV \quad \text{(Reference 6)} \tag{6}$$

where

$$f(V) = \frac{d}{dV}\left[1 - \left(\frac{N}{n_p}\right)\right] \tag{7}$$

Integrating Equation 6 between V_i and ∞, it can be shown that

$$\bar{V}_v = V_i + V_a \tag{8}$$

Considering the product $N_v \bar{V}_v$ in Equation 3, from Equations 5 and 8

$$N_v \bar{V}_v = n_p \left(V_i + V_a\right) \exp \left(-V_i/V_a\right) \tag{9}$$

Substituting $(1 - \rho_o/\rho_{o_n})/n_p$ for V_a, Equation 9 becomes

$$N_v \bar{V}_v = \left[V_i n_p + 1 - \left(\rho_o/\rho_{o_n}\right)\right] \exp \left[-V_i n_p/1 - \left(\rho_o/\rho_{o_n}\right)\right] \tag{10}$$

where

ρ_{o_n} = the density of nonporous propellant

From Equations 30 through 37 in Reference 5 it can be shown that

$$V_i n_p = 3C_2/D^2 \tag{11}$$

where

C_2 = a constant

D = the detonation velocity

Substitution of Equations 3, 10, and 11 into Equation 2 gives the final expression for c as a function of ρ_o, knowing f, C_2, ρ_R, and D:

$$c = \frac{1 - f}{1 + \dfrac{\left[\rho_o \exp 3C_2/D^2 \left(1 - \rho_o/\rho_{o_n}\right)\right]}{\rho_R \left[\left(3C_2/D_2\right) + 1 - \left(\rho_o/\rho_{o_n}\right)\right]}} \tag{12}$$

Equation 12 and others in this development will be written into a computer program to facilitate the calculations required to compute the values of many of the parameters discussed.

3.1.5   Error Analysis of Probe-Rasteroscillograph Data

The propagation-of-error technique has been applied to shock wave velocity vs distance data as derived from pin-probe/rasteroscillograph distance-time data. It can be shown that

$$\frac{V(D)}{D^2} = 2\left[\frac{V(x)}{(\Delta x)^2} + \frac{V(t)}{(\Delta t)^2}\right] \tag{13}$$

where the symbol $V(\ )$ refers to the variance, or standard deviation squared, of the parenthetical quantity, x is distance along the charge from the initiated end, t is the time of arrival of the shock front, and Δx is the interval over which the velocity is determined (Δt is the time interval associated with Δx).

If X is the distance from the sample top (initiated end) to the probe-entrance hole, δ is the displacement of the probe tip from a plane perpendicular to the sample axis through the probe-entrance hole, and ϵ is the effective displacement of the probe tip because of its deflection from the plane of the sample axis and probe-entrance hole and the curvature of the wave front, the distance x between the probe tip and the initiated end of the sample is

$$x = X + \delta + \epsilon \tag{14}$$

and

$$V(x) = V(X) + V(\delta) + V(\epsilon) \tag{15}$$

Evaluating the terms in Equation 15, we find that by definition,

$$V(X) \equiv \sigma_X^2 \tag{16}$$

and that

$$V(\delta) = \cos^2 \phi \ V(\ell) + \ell^2 \ V(\cos \phi) \tag{17}$$

and

$$V(\epsilon) \;=\; \frac{(r - \ell)^2}{R^2 - (r - \ell)^2}\; V(\ell) + \frac{\xi^2}{R^2 - \xi^2}\; V(\xi) \tag{18}$$

where

ϕ = the colatitude of the probe tip with respect to the probe-entrance-holes line

ℓ = is the length of the probe that is inserted into the sample

r = the sample radius

R = the radius of curvature of the wave front

ξ = the distance from the probe tip to the sample axis

$$\xi^2 \;=\; r^2 - 2\,r\,\ell \sin\phi \sin\theta + \ell^2 \sin^2\phi$$

where

θ = the longitude of the probe tip with respect to the plane tangent to the sample at the probe-entrance-holes line.

The geometrical relationships of the parameters discussed in Equations 14 through 19 are shown in Figures 1 and 2.

Assuming the following values for the parameters: σ_X = 1.59 mm, $\phi = \theta = 89^\circ$, $\sigma_\phi = \sigma_\theta = 1^\circ$, ℓ = 38 mm, σ_ℓ = 1.59 mm, for a sample of 5-in. diameter (r = 63.5 mm) the estimated coefficient of variance for velocity data is computed by the above equations to be 0.053. That is, the estimation of velocity has an expected error of ± 5.3%, which for a sample detonating at 4.1mm/μsec represents a standard deviation of 0.22mm/μsec.

An experimental study, using two sets of probes in a 5-in. diameter sample, was performed in conjunction with Subtask 3.2.2 testing, and from the analysis of these data a coefficient of variance was calculated to be 0.051. This result substantiates the essential accuracy of this analysis. The results have shown furthermore that greater efforts at accurate probe-placement are required. Design studies are now underway to achieve this objective.
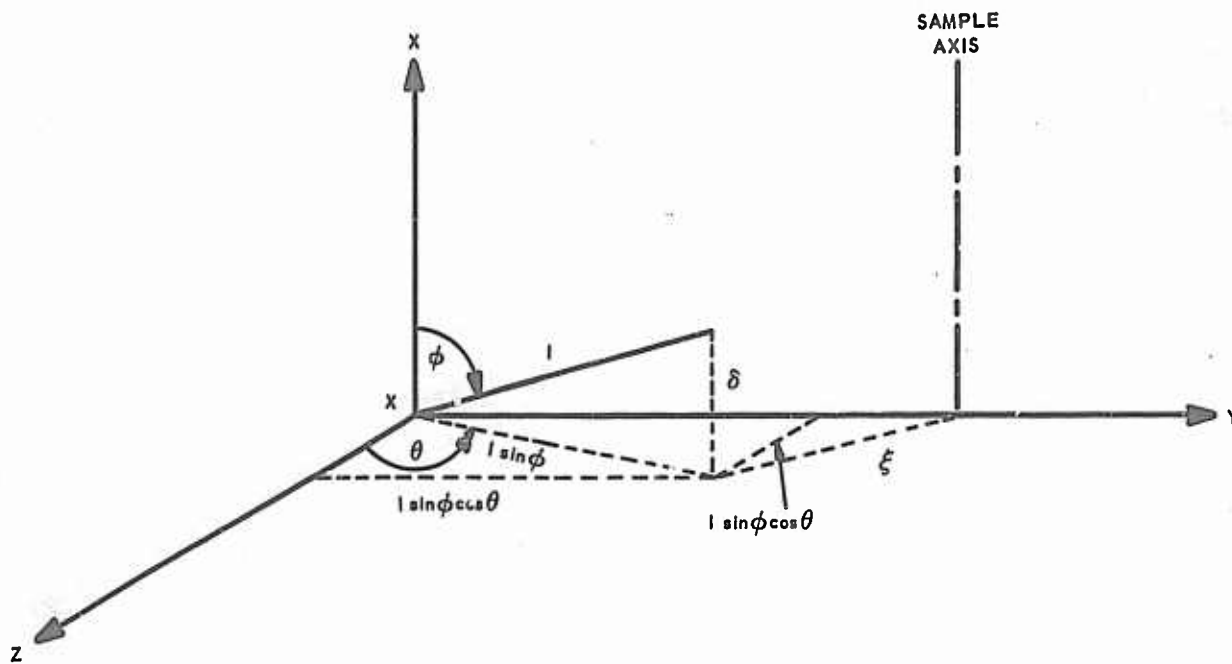
X-axis: Probe—entrance—holes line. increasing X is increasing
          distance from sample top.
XY-plane: Plane through sample axis and X.
XZ-plane: Plane tangent to sample at X-axis.
X   : Distance of probe—entrance hole from sample top.
ϕ : Colatitude of probe tip.
θ : Longitude of probe tip.
I   : Length of probe inserted into sample.
δ : Vertical displacement of probe tip.
ξ : Distance of probe tip from sample axis.

Figure 1.   Geometrical Significance of X, δ, and ξ .
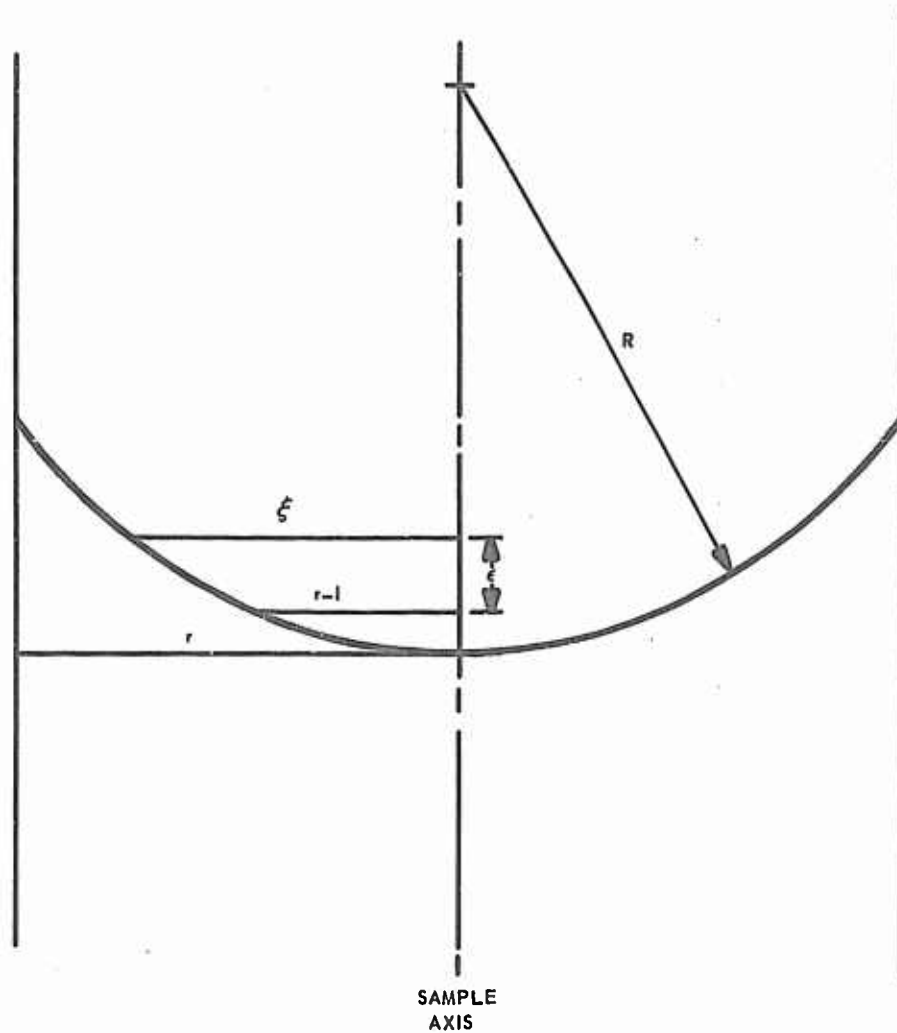
R : radivus of curvature of wavefront, exaggerated.
ξ : probe–tip to sample–axis distance.
r–l : minimum ξ
r : sample radius
ϵ : "equivalent vertical displacement" of probe tip, due to
its being δ–(r–l) farther from the sample axis.

Figure 2.   Geometric Relationship Between ϵ and ξ.

3.2 EXPERIMENTAL PROGRAM

3.2.1 Variance and Mean Critical Geometry

This subtask is designed to produce sufficient experimental data for a
statistical analysis of the variance in critical geometry test results.
Two configurations will be tested, a circular right cylinder and a
square right column.   The test samples are composed of AAB-3189 pro-
pellant, an Aerojet   RDX-adulterated AP-PBAN formulation con-
taining 9.2 wt % RDX explosive.   The material is the same as that used
in the critical geometry phase of AF 04(611)9945.   Its critical diameter
was found to be 2.71-in., with an estimated standard deviation of
0.06-in.

A 2000-lb batch of AAB-3189 was cast 17 January 1966.   This batch con-
sisted of (1) 50 cylindrical samples cast at 2.80, 2.74, 2.68, and
2.62-in. diameter, (2) six square columns (two each of the following
sizes: 2.4, 2.5, 2.6-in. square), and (3) eight samples for Subtask
3.2.3 tests.   The number of small cylinders   cast at each size   was
selected in accordance with statistical design to provide optimum
advantage to the determination of the variance.   While the critical diam-
eter may differ slightly from 2.71-in., it is not expected that it will
approach the extreme diameters chosen for this set of tests.

The square samples provide sizes for a crude bracketing of the critical
geometry for this shape.   The sizes are based on the results of tests
conducted with RDX-wax under AF 04(611)9945, which indicated that the
critical geometry of a square column is at least 10% below the critical
diameter.

The cured samples were subjected to X-ray inspection on 28 and 31
January 1966.   A large number of major voids (larger than 1/4 in.
diameter) were found in many of the samples.   Of the 50 cylindrical
samples intended for this subtask, only five were without voids.   The
cause was a vacuum leak in one of the two transfer-pot systems.   This
leak allowed air to mix with the viscous propellant during the casting
operation.

To prevent the recurrence of such an incident, the following procedure
has been incorporated into the casting operation.   A preliminary sample
will be cast and X-rayed immediately so that voids can be detected
before the full batch is cast.   The propellant transfer system will be
closely examined for any evidence of vacuum leakage.

The second casting of this batch has been scheduled for 1 March, so
that samples will be available for testing by approximately 1 April.

3.2.2   Mean Critical Diameter and Variance

The test objective is to accurately determine the critical diameter of an
adulterated AP-PBAN propellant containing 7.1 wt % RDX (AAB-3225)
and to estimate the variance of the results. The specific purposes of
these tests are: (1) to evaluate the ability of the detonation model to
predict the critical diameter of a specific material, (2) to obtain variance
data at an RDX-adulterant level other than 9.2%, and (3) to find by
extrapolation, the variance expected for 0% RDX (unadulterated) AP-
PBAN.

3.2.2.1   Test Results

The results of the 37 tests are shown in Table 4 and in Figures 3 and 4.
The mean critical diameter is 5.21 in., with a standard deviation of
0.06 in.

Since the predicted critical diameter was 6.00 in., most of the test samples
had to be cut and machined to smaller diameters for these tests. In the
process of making these modifications, it was necessary to limit the length
of some samples to four-diameter lengths; others were capable of being
machined to five-diameter lengths.

The data in Table 4 are arranged in order of decreasing diameter and,
for samples having the same diameter, they are arranged in order of
increasing density. The X-ray reports from this batch of propellant
showed that every sample had some major voids. All but three samples
had these voids in the upper 1- or 2-in. area. It was decided to proceed
with the testing of all but the worst sample (No. 37) since the orientation
of the sample in the test setup was in the as-cast position, with the
major voids at the upper end. The presence of holes at the initiated end
did not compromise the data taken over the lower half of the sample.

Table 4. Test Results, Subtask 3.2.2.

Diameter		Density	Result	Average Detonation Velocity[a]	Test No.
Mean (in.)	σ (in.)	(gm/cm^3)	(+ = Go 0 = No Go)	(mm/μsec)	
6.29	-	1.735	+	4.2	3.2.2.2
5.65	-	1.734	+	b	3.2.2.1
5.65	-	1.734	+	4.1	3.2.2.3
5.45	0.034	1.725	+	4.2	3.2.2.6
5.38	0.018	1.739	+	4.2	3.2.2.9
5.37	0.011	1.740	+	4.3	3.2.2.11
5.35	0.025	1.739	+	4.2	3.2.2.8
5.34	0.033	1.736	+	4.2	3.2.2.16
5.34	0.031	1.740	+	4.2	3.2.2.14
5.34	0.027	1.741	+	4.2	3.2.2.15
5.30	0.025	1.733	+	4.3	3.2.2.13
5.29	0.024	1.730	+	4.1	3.2.2.21
5.29	0.021	1.731	+	4.2	3.2.2.22
5.28	0.023	1.731	+	4.2	3.2.2.23
5.28	0.036	1.731	+	4.2	3.2.2.26
5.28	0.028	1.732	+	4.2	3.2.2.24
5.28	0.027	1.733	+	4.2	3.2.2.28
5.28	0.010	1.735	+	b	3.2.2.12
5.28	0.017	1.736	+	4.1	3.2.2.18
5.28	0.016	1.736	+	4.2	3.2.2.19
5.28	0.011	1.736	+	4.2	3.2.2.20
5.28	0.018	1.737	0	c	3.2.2.17
5.28	0.008	1.739	0	c	3.2.2.10
5.27	0.008	1.743	0	c	3.2.2.5
5.26	0.040	1.730	+	4.1	3.2.2.25
5.24	0.024	1.733	+	4.0	3.2.2.27
5.24	0.025	1.733	+	4.1	3.2.2.29
5.02	0.010	1.729	0	c	3.2.2.7
5.02	0.016	1.736	0	c	3.2.2.37
5.01	0.003	1.733	0	c	3.2.2.4
5.01	0.016	1.735	0	c	3.2.2.30
4.86	0.011	1.739	0	c	3.2.2.35
4.85	0.015	1.735	0	c	3.2.2.34
4.85	0.014	1.736	0	c	3.2.2.36
4.75	0.011	1.738	0	c	3.2.2.31
4.74	0.008	1.731	0	c	3.2.2.32
4.50	0.015	1.735	0	c	3.2.2.33

[a] Calculated from probe data. Obtained over region from two diameters down, to charge bottom. Accuracy of measurement is ± 0.1 mm/μsec.
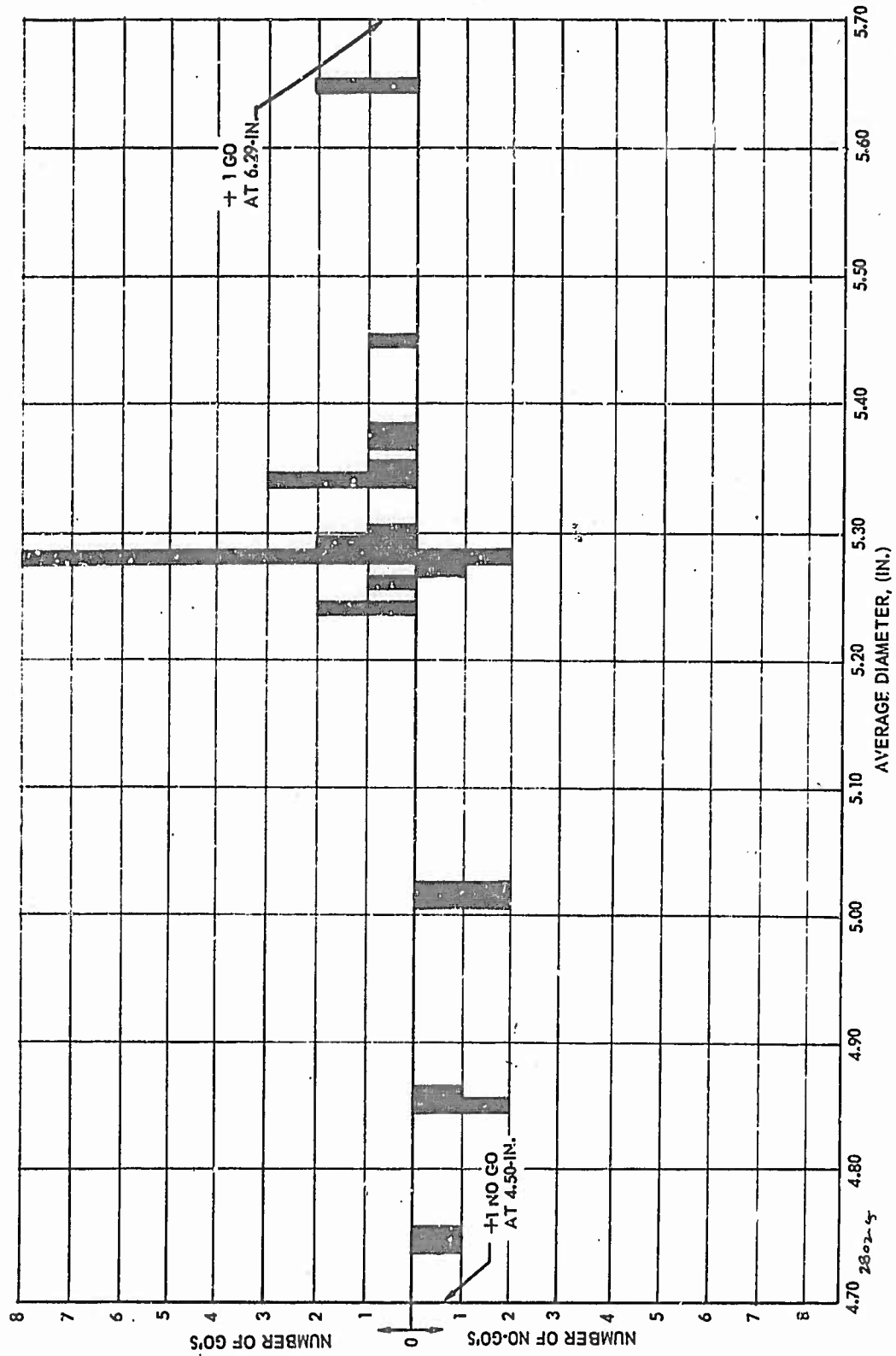
[b] No raster record.

[c] Not applicable.

Figure 3. Critical Diameter Results -- 7.1% RDX-Adulterated AP-PBAN.
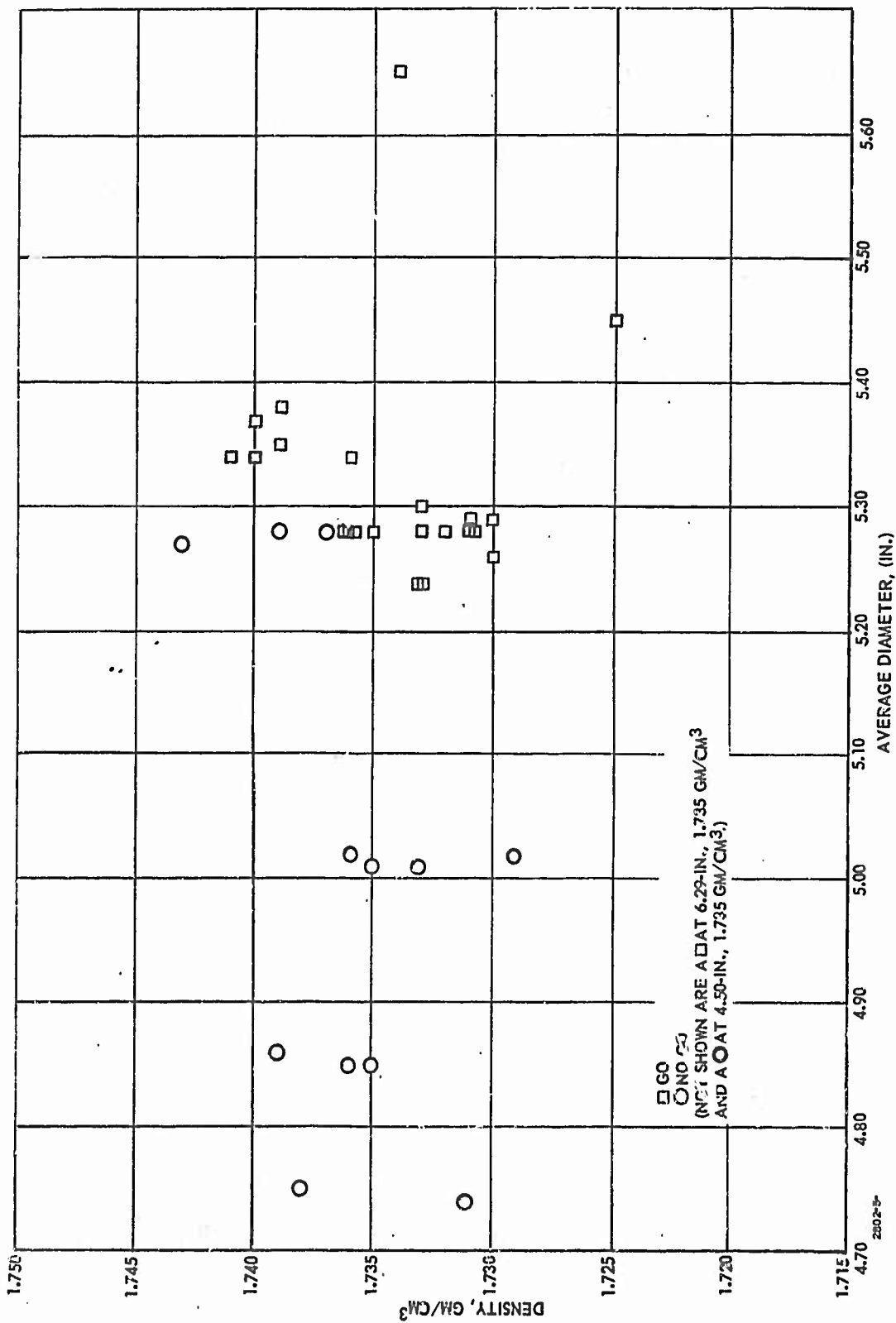
Figure 4. Test Results, Subtask 3.2.2.

3.2.2.1.1 Density Measurements

The density measurements on these samples yielded an average density of 1.735 gm/cm^3 with a standard deviation of 0.04 gm/cm^3. Using these data and assuming the maximum (no pores) density to be 3 σ above the mean, the data indicate that ρ_{o_n} is 1.747 gm/cm^3.

Observations during the casting proceedings, where slumping of the propellant was reported, gave another source by which the maximum density could be estimated. In the 6-in. diameter samples, when vacuum was released, the propellant surface dropped about 3-in. This drop can be related to the volume of included gas. In subsequent calculations using this data, a porosity of 0.008 is predicted. Assuming that this porosity is that equivalent to a density of 1.735 g/cm^3, the nonporous density becomes 1.749 g/cm^3. This agrees with the value calculated from density measurements even though it was based on approximate information. However, when these values are used with Equation 2, a value of c is calculated which equals 1.4 x 10^{-4}. This is not in agreement with the value of c which statistically best-fits the critical-diameter data. Further study of this problem is being conducted.

3.2.2.1.2 Velocity Accuracy

To test the analysis that is presented in Section 3.1.3, a test was conducted using a 5-in. diameter sample. Probes were placed along two diametrically opposite lines down the sample, with probes placed at corresponding distances from the top. By comparing the velocities derived across each pair of intervals, the coefficient of variance was calculated to be 0.051. The detonation-velocity vs distance record is shown in Figure 5.

3.2.2.2 Conclusions and Future Work

Statistical analysis of the AAB-3225 data presented in Table 4 and Figures 3 and 4 yielded a mean critical diameter of 5.21-in., with a standard deviation of 0.06 in. This critical diameter is about 13% below the theoretically predicted value of 6.00 in. The standard deviation, on the other hand, is the same as that derived for AAB-3189 during the SOPHY I critical-diameter tests. This agreement indicates that variance is relatively constant in the region; 7.1% to 9.2% RDX (5.21- to 2.71-in. critical-diameter).
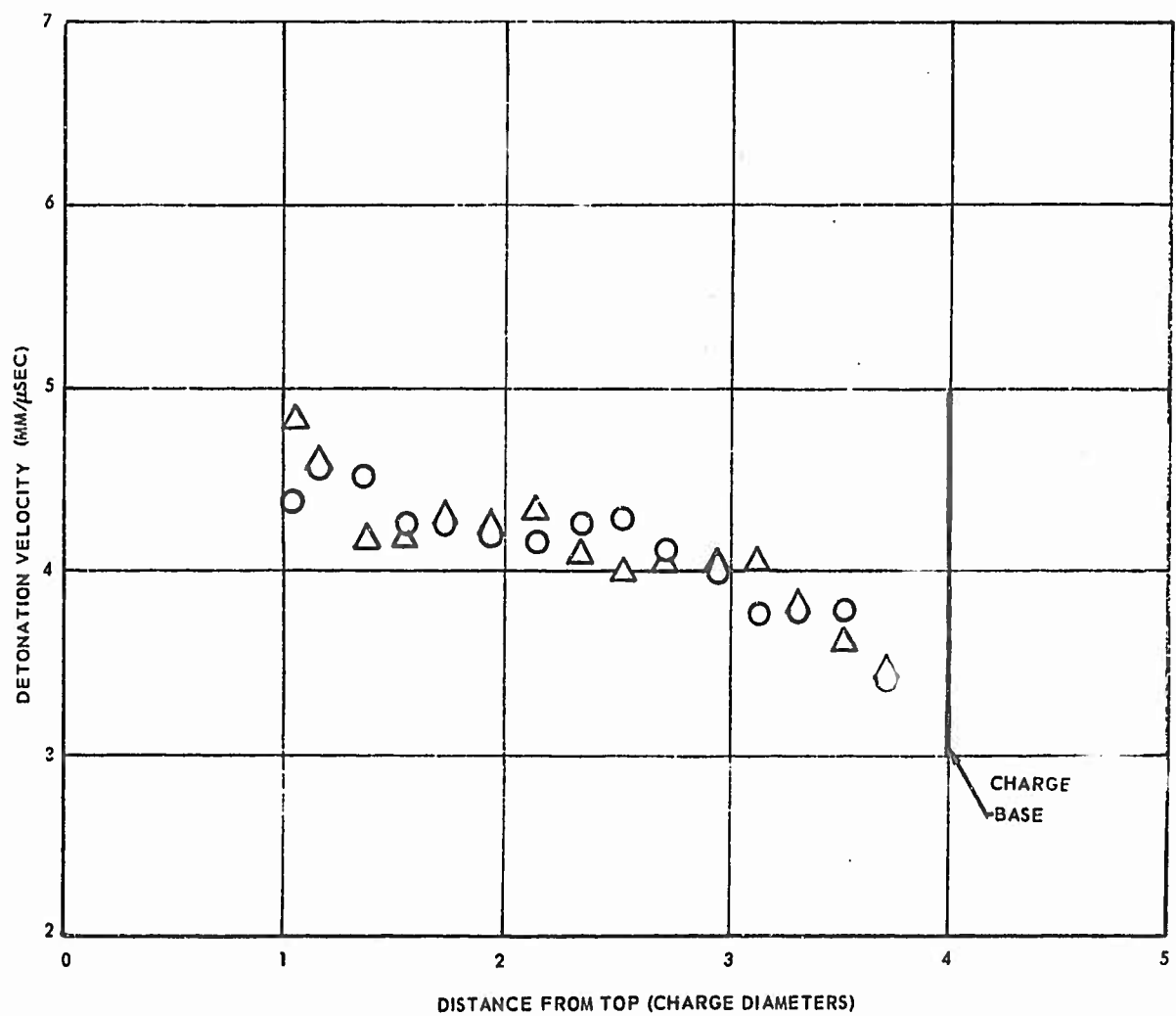
Figure 5. Velocity-Distance Record -- Test 3.2.2.37: Dual Instrumentation, 5.02 In. Diameter, 1.736 gm/cm^3; Result, No Go.

The surprisingly low value of the standard deviation implies that either the critical diameter of the material is not greatly affected by the presence of a number of voids of the size present in these samples, or the void effect was unusually consistent from sample to sample. If the latter is true, the lack of agreement between the experimental data and the model may be attributed to the effective lowering of the critical diameter by the porosity.

The uncertain results from these tests forced the re-casting of this batch on 18 February 1966. No propellant slumping was observed when vacuum was released. The sample sizes selected span the region from 5- to 7-in. as follows: two at 5 in., two at 5-1/4 in., two at 5-1/2 in., three at 5-3/4 in., five at 5-7/8 in., four at 6 in., five at 6-1/8 in., two at 6-1/4 in., two at 6-1/2 in., and two at 7 in. Should the initial tests of these samples support the current critical-diameter estimate, it may become unnecessary to test the entire batch.

3.2.3 Detonation Velocity as a Function of Size

Preliminary tests have been performed in order to perfect the probe and electronic circuitry necessary for reaction-zone measurement. These tests were formed to determine detonation velocity and reaction-zone thickness as functions of size.

Special ionization probes, constructed from drill rod, in combination with a constant-voltage source, in a voltage-divider circuit, are used for this system. The voltage across a known resistor placed in series with the probe is monitored on an oscilloscope. The changes in voltage across the resistor are inversely related to changes in resistance across the probe gap during passage of the highly-ionized reaction zone. Assuming constant ion-concentration throughout the reaction zone, the voltage drop across the resistor is proportional to the length of the probe inside the reaction zone. Thus the shape of the pulse on the oscilloscope is a projection of the reaction-zone profile in the sector that is intercepted by the probe. The amplitude of the pulse can be equated to the distance the probe is inserted into the sample. (The maximum distance is the sample radius, by symmetry.) With the wave moving at a constant velocity, time units can be converted to distance units in the direction of the sample axis. The time axis (zero volts) is equivalent to a line through the probe tip parallel to the axis. A representation of this concept is shown in Figure 6.
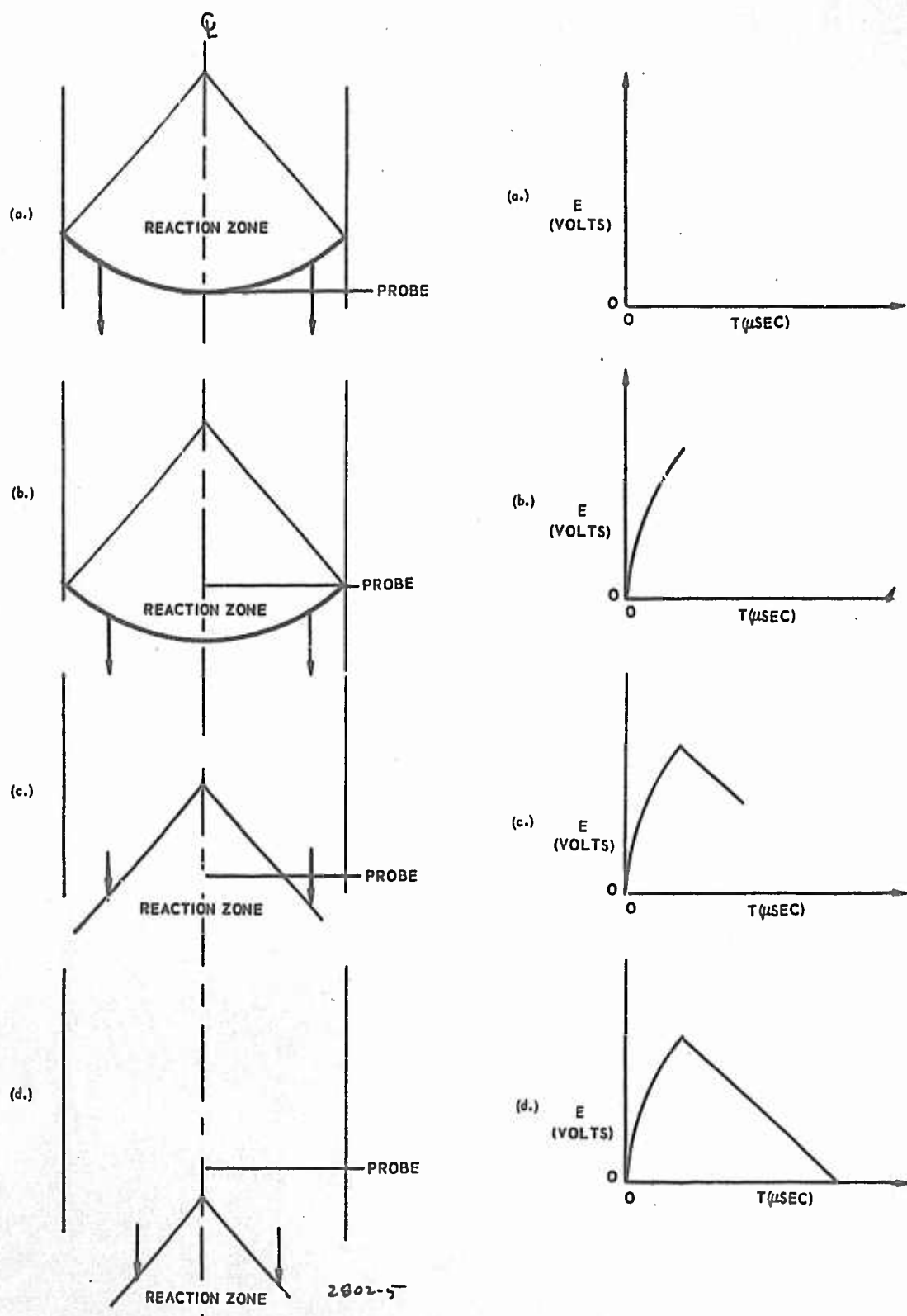
Figure 6.   Correlation Between Probe Position in Reaction Zone and
Oscilloscope Pulse Shape.

The results from one of the preliminary tests are shown in Figure 7, where the close agreement between probes inserted to different depths is shown. One probe was inserted to the sample axis. The pulse resulting from this probe will show the profile of one-half the reaction zone. The second probe was inserted one-half radius toward the axis; its output will show the shape of the outer portion only of the zone which envelopes the probe. The overlapping of these traces, when an appropriate scale adjustment was made, indicated good support for the basic hypothesis upon which this method is based. The only adjustment required was to shift zero-time on the pulse obtained from the shorter probe to that time on the longer pulse which represented the time of arrival of the front to the tip of the short probe. The agreement in rising and falling slopes was excellent.

Subsequent tests of this sytem, with an explosive linewave generator, showed that the inherent rise time was better than $0.2\,\mu sec$. Since the rise times of these pulses was near $4\,\mu sec$, no serious masking of the wavefront curvature could be attributed to the electronic system, and therefore considerable confidence could be placed in the curvature deduced from the pulse shape.

4.   LARGE CRITICAL-DIAMETER TESTS

The five segments have been cast in preparation for testing the 72-in.-diameter unadulterated propellant sample. The segments have been removed from the curing ovens for final surface finishing. X-ray inspection and preparation for shipment to Area 1-36D, AFRPL, are the items on the immediate schedule. The target date for the test remains set at 25 March 1966.

The vacuum chuck fabrication is completed and the fixture is ready to be checked out. The other handling fixtures also have been fabricated.

The TNT booster, consisting of stacked segments to approximate a 3:1 cone, has been cast at Aerojet's Chino Hills facility, along with a 2-ft diameter x 8-ft high TNT cylinder which is to be fired in early March in order to check out all instrumentation systems for the 72-in.-diameter test.
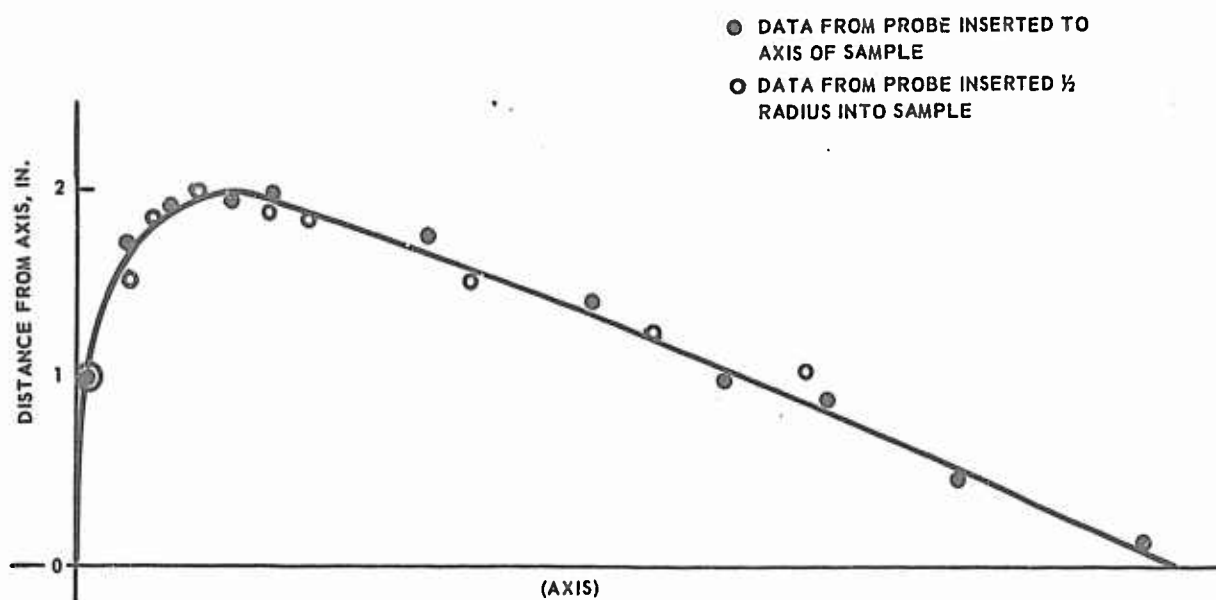
2842-2-7-1

Figure 7. Mapping of Reaction Zone Profile, 4-in. Diameter Sample.

Of considerable importance in the calibration test is the checkout of the detonation-velocity probe systems. Several changes have been made to the system that was employed in the 48-in.-diameter tests performed on AF 04(611)9945. These will be evaluated in the TNT shot, and the system that performs the best will be used in the 72-in.-diameter test. The problem experienced last year was the reception of extensive noise, which made the rasteroscillograph records difficult, and in some cases impossible, to read.

Aerojet personnel are currently involved in the preparation of the test site for these two tests. Preparation includes considerable modification of the electronic instrumentation to improve the capabilities of the area and its efficient operation. Instrumentation pits are being cleaned out and new lids, to permit more effective sealing of the pits, are being fabricated and will be installed soon.

5.   PROPELLANT DEFECTS STUDY

The literature search is continuing. A complete summary and bibliography of the search will be issued upon completion of this project.

An experimental program to develop and evaluate means of producing and characterizing propellant with defects will soon begin. Efforts have been limited to a study of the directions most likely to be successful in this subtask.

After discussions with Dr. Frank Hepner of the Propellant Development Department at Research and Technology Operations, Sacramento, California, it was decided that this group has both the experience and capabilities to undertake the major portion of this investigation. Work will commence after the defects study program details have been agreed upon. It is expected that the planning of this effort will require most of the month of March, which will make 1 April the target date for beginning the study.

6.   FUTURE PLANS

During the next quarterly period, March through May 1966, the following work will be performed:

a.   Completion of the variance and mean critical-geometry tests (Subtasks 3.2.1 and 3.2.2).

b.   Near-completion of Subtasks 3.2.3 and 3.2.4*.

c.   Firing of the 72-in.-diameter test, selection and casting the second large critical-diameter sample.

d.   Certain parts of the Phase II test program may be initiated depending on the results of the 72-in.-diameter test.

e.   Continuation of the propellant defects literature search.

f.   Initiation of the propellant defects experimental program.

g.   Continuation of microscopic analysis of each batch of adulterated propellant, for information pertinent to the estimation of the parameter c in the detonation model.

h.   Use of RUBY to compute detonation properties of composite propellant.

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*Jetting phenomena study.

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13 ABSTRACT

Theoretical and experimental investigations of the detonation characteristics of solid composite propellant rocket-motor grains are described. Statistical variance in critical-diameter data was determined for an RDX-adulterated AP-PBAN propellant. Preparations for a large critical-diameter test, involving unadulterated AP-PBAN propellant, are discussed.

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KEY WORDS	LINK A		LINK B		LINK C	
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